J. S. Boland
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Third Annual Houston Conference

on

COMPUTER AND SYSTEM SCIENCE

University of Houston
Cullen College of Engineering

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COMPUTER AND SYSTEM SCIENCE

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PREFACE

The Third Annual Houston Conference on Computer and System Science was held on April 26 and 27, 1971, at the University Center, University of Houston. The papers describe new results in various fields in computer and system science: computer systems, computer languages and programming, switching and logical design, control systems, biological control, communication sciences, artificial intelligence, pattern recognition, computer simulation, computer graphics, and biomedical applications of computer and system science.

I would like to thank Dean C. V. Kirkpatrick of Cullen College of Engineering and Dr. D. R. Williams, Chairman of the Electrical Engineering Department, for their encouragement and support. Also, I would like to thank Professor L. A. Zadeh who organized the session "Frontiers of Computer and System Science" and the Houston Engineering Research Corporation (HERCO), particularly, Mr. A. H. McMorris, Senior Vice President, who provided the interactive graphic CRT demonstration for the Conference, and Professors W. L. Anderson, J. K. Aggarwal, R. R. Mobler, and J. B. Wyatt, Director of Computing Center, and many Electrical Engineering faculties for their eithusiastic support. Special thanks are due Mrs. Linda Vasquez who assisted with conference arrangements and the editing of this proceedings. Finally, it gives me pleasure to acknowledge the encouragement and invaluable suggestions of Professor M. E. Van Valkenburg during the preparation of the Conference.

Samuel C. Lee
Conference Chairman

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A SYSTEM FOR THE DIGITIZATION, STORAGE, AND DISPLAY OF IMAGES***

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ABSTRACT

A system has been designed, built, and utilized for digital image scanning, storage, and display of pictorial images. The system described was built specifically for processing medical radiographs, but can be used for any images which are in a suitable form. Major system components include two separate digitization devices, a controlling computer, an image library, and three distinct display devices.

The two digitization devices (scanners) include a flying-spot scanner and an image dissector scanner. The three image display devices used are a Dicomed image display, a conventional CRT device, and a newly designed, high resolution, high tonal TV display that involves high speed disc storage and includes interactive capabilities. Various tradeoffs are present when one is to choose which of the various devices to use in a particular application. These relative advantages and limitations will be considered in this paper.

The control computer is a Systems Engineering Laboratory (SEL) 840A. It is a small scale machine that includes digital to analog, analog to digital, and digital to digital channels in its data acquisition system. The control programs are written in SEL Mnembler (Assembler) language and their makeup will be considered here.

Sets of magnetic tapes make up the image library. They are available to researchers covering a wide range of image processing applications. An indexing system that allows researchers to effectively select images has been implemented, making this system an effective tool for generating large quantities of digital images for computer analysis.

Finally, the system has the capabilities of performing several elementary image analysis procedures which are desirable to include in an online fashion. Some of these are mentioned.

INTRODUCTION

During the past five years there has been a tremendous upsurge of interest in computer analysis of digital imagery. This interest has ranged from communications applications and resulting studies of bandwidth compression (1,2,3), to image enhancement techniques (4,5), and more recently has included some highly successful medical applications (6,7). There has been a similar increase in the availability of equipment and instrumentation to perform the tasks of image digitization (scanning) and image display. It is not always apparent, however, just what equipment is necessary for a particular application. The Image Analysis Laboratory at the University of Missouri-Columbia (IAL/UMC) has designed, built, and utilized a system for the digitization, storage, and redisplay of digital images which incorporates a variety of scanning and display devices. The relative features of these devices as well as the type of control programming required by them is the subject of this discussion. The system has proven itself an effective tool for generating quantities of digital images for computer analysis.

SYSTEM DESCRIPTION

The system as depicted in Figure 1 performs three categories of operations: (1) the conversion of images in the form of film transparencies into digital arrays of numbers; (2) the storing of these arrays in an orderly fashion to facilitate retreival for use by researchers; and (3) the redisplay of these and other picture arrays either to produce a photograhic copy or for direct viewing. The conversion of film to numbers is accomplished either by a flying spot scanner (FSS) or an image dissector scanner (IDS) which utilizes an image dissector camera in the digitization. Both of these devices operate under the control of an SEL 840A digital computer which also handles the flow of data from scanner to magnetic tape unit.

The digital images are recorded on 800 BPI magnetic tape during the scanning process, becoming permanent entries in the image library which IAL/UMC has generated. The library at present consists of several hundred digital images stored on IBM-compatible magnetic tape in a special library format that facilitates locating and using every entry in the library. An identification record containing scanning parameters and content information is written at the beginning of each image on a library tape. A library index in punched card form contains identical information and is updated as new images are recorded. Line printer copies of this cross-referenced index are distributed to all users or prospective users of the image library. Through the use of this library digital imagery becomes available to any person at IAL/UMC who needs data for image analysis work.

The third function which the system performs is the reconstruction of real images from digital form. Three separate devices accomplish this. The first device is a Hewlett Packard 1300A X-Y display scope with a z-axis input. Second is a Dicomed/30 Image Display, manufactured by Dicomed Corporation of Minneapolis. The third device is a new type of digital image display which was developed at IAL/UMC. It utilizes a high speed disc memory which is filled at slow data rates, then dumped at high data rates as video information to a high resolution, high tonal television monitor display. Another distinguishing feature of this device is its interactive capabilities. Through the use of a joystick the operator may extract certain features of the displayed image and enter these into the computer.

Central to the operation of both scanning and display devices, the SEL 840A digital computer acts as controller and information channel for the system. The SEL 840A is a small scale computer with a memory cycle time of 1.75 microseconds and 16K of 24 bit word memory. A minicomputer could also perform the necessary tasks. An IBM compatible tape drive is necessary for library creation.

DIGITIZATION DEVICES

Flying Spot Scanner (FSS)

The flying spot scanner has seen wide use as an image digitizer. Serving as two devices in one, the FSS can also reconstruct hard copy photographic images from digital form. For this reason the FSS is sometimes chosen as both the digitizing and reconstruction instrument in many image analysis applications.

The basic components of an FSS system are shown in Figure 2. When the transmittance at a pair of particular coordinates on the film is to be measured, a dot is illuminated on the CRT at a corresponding location. The position of the dot is controlled by X and Y deflection voltages which

are usually generated by digital-to-analog converters. At IAL/UMC these converters are an integral part of the SEL Computer Data Acquisition System which operates as a peripheral device to the SEL 840A. An image of the computer-positioned dot of light is focused upon the film by the lens. The amount of light passing through the film is measured by a photomultiplier tube positioned behind the film. This signal contains some error due to the fact that the brightness of the dot is not entirely uniform over the surface of the CRT. To account for this error the beam is interrupted by a beam splitter and the intensity of the dot is measured by a second photomultiplier. Both signals from the photomultiplier tubes contain a good deal of electron shot noise. This must be removed by extensive filtering prior to analog-to-digital conversion of the signals. The ratio of transmitted signal to reference signal, calculated either digitally or by analog techniques, is the quantity of interest. This measurement is repeated rapidly for all of the locations in the picture raster.

To reconstruct photographs from digital images, unexposed film is placed in the FSS and the dot intensity and position are controlled so as to expose the film. The reference photomultiplier measures the amount of exposure that the film is receiving.

Factors affecting the resolution or ability to delineate fine detail of a flying-spot scanner system include CRT spot size, lens resolution, film image contrast and sharpness, and phototube signal-to-noise ratio (SNR) (8). The resolution obtained in an FSS system seems to be proportional to the cost spent in constructing the device. An inexpensive, low resolution FSS has been implemented at IAL/UMC. It will scan 3" x 3" film size at a limiting resolution of 256 samples across the film. This has proven quite sufficient for low-resolution image analysis applications. Very high resolution has been attained elsewhere but at a tremendous increase in cost (8).

An important advantage of an FSS system is that color image scanning and reconstruction can be handled very easily. By the use of a "white" light-producing phosphor, suitable filters, and multiple scanning techniques, color images can be stored and reconstructed. This capability is mandatory for image analysis when image color is an important feature. The ability to include a reference photomultiplier for real-time non-uniformity correction is another definite advantage. This type of compensation cannot be achieved with some scanning devices. Additional advantages include high obtainable resolution and the ability to scan very small format films. A disadvantage of the FSS system is that it is difficult to scan large format films such as full size medical radiographs.

<u>Image Dissector Scanner (IDS)</u>

The image dissector scanner (Figure 7) is the second and most flexible digitization device utilized at IAL/UMC. The distinguishing component of the IDS system as depicted in Figure 3 is the vidissector camera, manufactured by International Telephone and Telegraph Industrial Laboratories. The camera employs an image dissector tube to sample the input image.

The image dissector has been described as a photomultiplier with a small electronically movable photocathode area, thus acting as an all-electronic low-inertia microphotometer (9). The image to be scanned is focused by the camera lens onto a 1.75 inch circular photocathode. Elec-

trons are emitted from the back of the photocathode, forming an electronic image with current density modulated according to the image input. The electron image, focused by magnetic deflection, falls upon an aperture plane at the other end of the drift tube. The aperture "samples" the image by allowing only a small, well defined area of the electron image to pass through. The sampled photoelectrons are then multiplied by an electron multiplier by a factor of approximately 5 x 10^5. The entire electron image is deflected allowing the aperture to sample different points in the picture.

At IAL/UMC the input image is a medical radiograph measuring 13½ by 13½ inches and illuminated from behind by a DC powered, high intensity light source. The camera deflection signals are generated by the SEL computer and converted to analog in the SEL data acquisition system. Deflection buffer amplifiers are used to adjust the amplitude and offset of the deflection signals. Eleven bit DAC's are used to allow for scanning rasters of 2048 x 2048 points, although this actually exceeds the resolution of the camera.

The noise current present in the video output of an image dissector camera system can be attributed to random fluctuations of photo-electrons entering the aperture, modified by the statistical noise properties of the electron multiplication process. It is necessary to remove this noise prior to analog-to-digital conversion. This is accomplished by integrating the video signal for a suitable length of time. The resulting signal-to-noise ratio becomes a function of tube construction, input image brightness, and integration time and can be expressed as (10):

$$S/N\ (RMS) = \sqrt{\frac{I(\sigma-1)\ \Delta t}{e\sigma}}$$

where

$$I = \frac{TJ_k \pi d^2}{4}$$

T = mesh transmission = 0.5
J_k = photocathode current density (function of image brightness)
σ = gain/stage of photomultiplier
$e = 1.6 \times 10^{-19}$
and Δt = integration time (inches)
d = aperture diameter (seconds)

At IAL/UMC the integrate time can be selected, but 800 microseconds is a common time. This relatively long integrate time gives a S/N ratio of over 40 DB for a relatively bright input image. This has been verified by digital frequency analysis of the video signal.

The resolving capabilities of an image dissector are determined by the shape and size of the dissecting aperture (9). IAL/UMC uses a circular aperture of diameter 1 mil. This configuration gives a resolution modulation amplitude of 39% at 1000/TV lines per inch on the photocathode. The usable diameter of the photocathode is 1.4 inches, given a resolution of 1400 TV lines across the image diagonal.

Logarithmic conversion via a logarithmic video amplifier allows recording of the optical density of a film, rather than transmittance. This is an optional feature, allowing better grey shade condition in the darker

areas of a film. An 11 bit analog-to-digital converter is used for the video signal, a more than sufficient number for grey-shade rendition. However, this allows less critical adjustment of the video signal amplitude to insure sufficient quantization levels.

A definite advantage of the IDS system over the FSS system is its ability to scan large format films, such as 14 inch by 14 inch radiographs. With proper optics the IDS can scan small format also. A disadvantage of the IDS system is the inherent non-uniformities in the illuminating light source. Cathode non-uniformity can be typically $\pm$ 15% over the usable surface, while light source non-uniformity depends upon construction of the source. In the FSS system non-uniform CRT response could be compensated for in real time by the reference photomultiplier. For the IDS the correction had to be made by scanning a blank film and then subtracting or dividing each subsequent scan, point by point, by the reference image array. Subtraction was used for density scans, while division must be used for transmittance scans.

DISPLAY DEVICES

Conventional CRT

The crudest form of digital image reconstruction employed at IAL/UMC is a Hewlett-Packard 1300A X-Y display scope with a DC coupled intensity control. X and Y deflection signals generated by the computer position the beam on the face of the 8 inch by 10 inch scope. The dot intensity can either be pulse amplitude modulated or pulse length modulated. The slow (40 KHZ) D to A speed of the SEL data acquisition system requires that a time exposure photograph be made to actually view the resulting image. CRT spot size also limits the resolution to something under 512 picture points per picture width. Both of these limitations make for a rather marginal image display device, but one which will suffice for some applications.

DICOMED 30 Image Display

The second display device used in the Image Analysis Laboratory system is one that is designed and manufactured specifically for displaying digital images (Figure 6). The DICOMED/30 Image Display is a product of the DICOMED Corporation of Minneapolis, Minnesota. The device interface with the computer is purely digital and is operated like a computer peripheral. The display utilizes a unique type of CRT called a dark trace storage tube which uses a scotophor instead of a phosphor to produce the image. The scotophor is deposited upon the 8 inch viewing surface of the tube. When struck by the electron beam it becomes more opaque and remains so until it is erased by thermal neutralization. This is in contrast with a phosphor CRT which glows only momentarily when it is struck by an electron beam. This almost infinite persistence characteristic of the dark trace storage tube makes it ideal for converting digital images into a usable form. Under program control the DICOMED display "paints" an entire image, one raster point at a time, upon the CRT viewing surface. When illuminated from behind by a viewing light, the CRT face portrays the reconstructed image which remains in full view without need for refreshing by the computer. Thus, with this device, the user can either view the reconstructed image directly or he may desire to make a photograph of it.

The DICOMED display has a set 1024 by 1024 square raster superimposed on the 8 inch circular viewing surface. With digital pictorial data that consists of fewer raster points only a portion of the viewing area need be

utilized or, if one wishes, the smaller rasters can be interpolated at display time up to the set 1024 point raster of the display.

The display and its associated control program can reconstruct an image from magnetic tape in approximately 100 seconds, the time being nearly the same regardless of raster size. The image that is produced has high resolution and can contain up to 64 distinct shades of grey. The contrast ratio of the display is a maximum of 3 to 1 but this can be improved upon when producing "hard copy" by using high contrast film and high contrast paper to print the resulting pictures on. The erasure of images is automatic and takes about 15 seconds to complete one erasure. This is accomplished by heating the scotophor until the scotophor returns to its neutral state. The storage property of the DICOMED Image Display makes it ideal for converting digitally coded pictorial data into a useful form.

Disc Memory-TV Display

The preceding discussions noted that both the CRT and DICOMED/30 displays were relatively slow devices and that the DICOMED display suffered somewhat from low contrast ratio. Both of these problems have been overcome with the high speed disc-image display system recently designed and implemented at IAL/UMC (Figure 8).

Data transfer rates of conventional magnetic tape drives and digital I/O channels are much too slow for flicker-free CRT or TV display of high resolution digital pictures. In the high speed disc-display system, digital picture information is fed to a disc memory at these slow rates, then dumped repeatedly to a television monitor at rates high enough to produce a flicker-free image. The system operates as shown in Figure 4. The image data is read from magnetic tape at interface rates, then dumped via the SEL DAS digital I/O channel into a 72 x 16 bit buffer array. When full, the array is dumped to the disc. The disc is a Data Disc which has parallel read/write capabilities on 72 tracks of 100,000 bits per track. The disc will hold up to three 525 line pictures or one 945 line picture at a time. Once the disc has been filled with the desired picture information, the computer is free to perform other tasks, as the display then acts as a stand-alone facility. The image information is read in parallel by 72 heads, converted to analog form by high speed DAC's, and displayed as an image on the television monitor at 30 frames per second with interlaced alternate frames, producing a flicker-free image. A control switch determines which of the three 525 line images on the disc is to be displayed.

The television monitor itself has a resolution of 1800 TV lines per picture width, adequate for many applications. The monitor also has a contrast ratio of over 10 to 1, a substantial improvement over the DICOMED display. Also, picture fill time for a 525 line image is less than 20 seconds compared to 100 seconds for the DICOMED/30 display.

One of the most distinguishing features of this image display system is its interactive capabilities. Although interactive displays are quite common in graphics applications, an interactive high tonal, high resolution image display is a rarity.

This interactive mode is accomplished by using an interactive module which employs a joystick to position a dot of light on the television monitor. The joystick generates X and Y analog voltages which are digitized

and compared with the X and Y coordinates being displayed on the monitor. When a match occurs, the image information at the location is ignored and a white dot displayed instead. The X and Y coordinates of the dot may be displayed on a digital readout panel or they may be sent upon command into SEL memory via the digital channel on the data acquisition system. In this manner objects in the image field may be outlined and that outline recorded in computer memory or disc. Another use would be to take measurements of objects in the image.

The fast display speed, high contrast, and interactive mode make the disc image display an outstanding addition to the display hardware at IAL/UMC.

CONTROL COMPUTER

Hardware

The SEL 840A digital computer proved to be an effective machine for controlling and handling data transfer to and from the various devices described above. The SEL 840A is a fast (1.75 microsecond memory cycle time), general-purpose, 24-bit binary computer and the IAL/UMC installation included an ASA 33 teletype, disc file, magnetic tape unit, printer, high speed paper tape reader, card reader, and a SEL Data Acquisition System (DAS). The DAS included four 11-bit digital-to-analog converters, six analog-to-digital converters, and two input and output 24 bit digital channels. Of these peripherals, only the teletype, tape drive, disc, and DAS are actually utilized by the image scanning, storage, and display system.

Software

The various control programs reside upon the disc file and are called into memory for execution by teletype command. The programs are all written in SEL Assembler language, the largest of which occupies only 4K of computer core storage. A much smaller machine than the SEL 840A (16K) could be used for this application. The programs themselves perform three categories of functions: (1) data transfer to and from peripherals and devices; (2) data formatting; and (3) timing control. Data transfer consists of either initiating block transfers or single word transfers to and from the converters and digital channels in the DEL DAS. Data formatting usually involves quantization and adding of control bits. Finally, the timing control function of the programs includes integration control and the synchronization of single word transfers.

When displaying an image on any of the displays, several on-line image analysis procedures are included as user options. The first of these is a process which calculates the histogram or the distribution of picture points for all shades of grey, of the picture being displayed. This histogram is then printed out on the line printer in the form of a graph.

A second type of on-line picture processing available consists of variable quantization. The user can specify the number of bits he wishes to represent each picture point, from the maximum of 6 to 8 down to 1 bit picture representations. This allows the viewer to get a better feel for the magnitudes of the various picture elements.

CONCLUSIONS

The image analysis laboratory at the University of Missouri-Columbia has sought to build a highly flexible image scanning, storage, and display system that could be utilized in a wide range of image analysis applications and research. This has been accomplished through the use of multiple scanning and display devices, and the use of an image library for data

storage and retrieval. For systems built for a specific image analysis application, the instrumentation chosen will be application-dependent and will be selected on the basis of resolution, speed, and expense.

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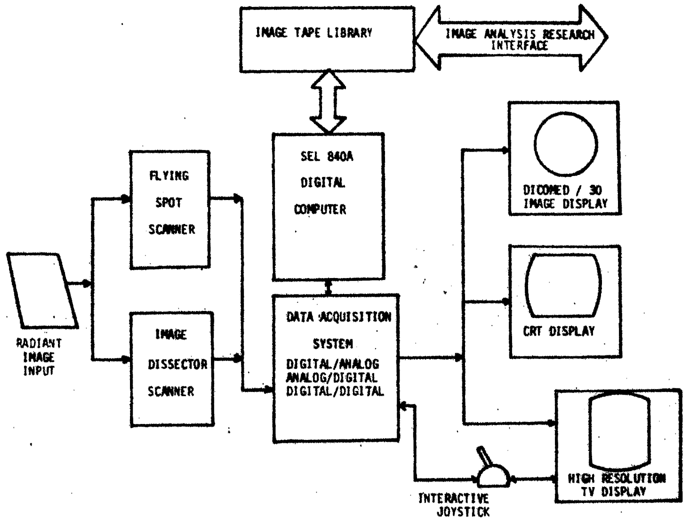


DIGITAL IMAGE SCANNING, STORAGE, AND DISPLAY SYSTEM
FIGURE I

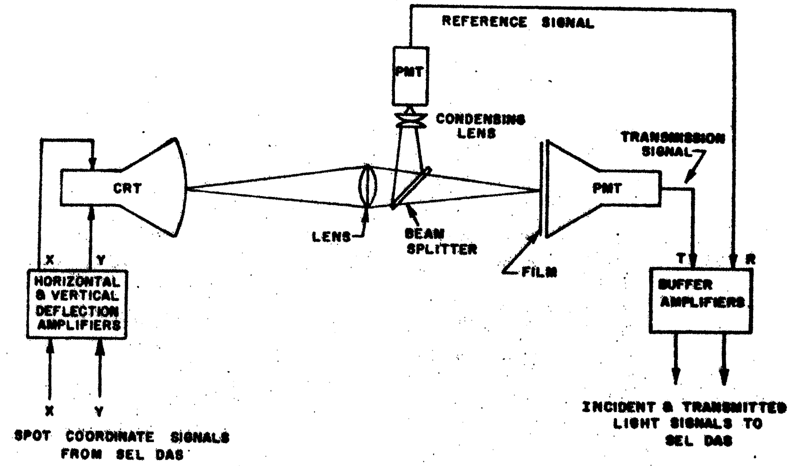


FIGURE 2 FLYING SPOT SCANNER (FSS)

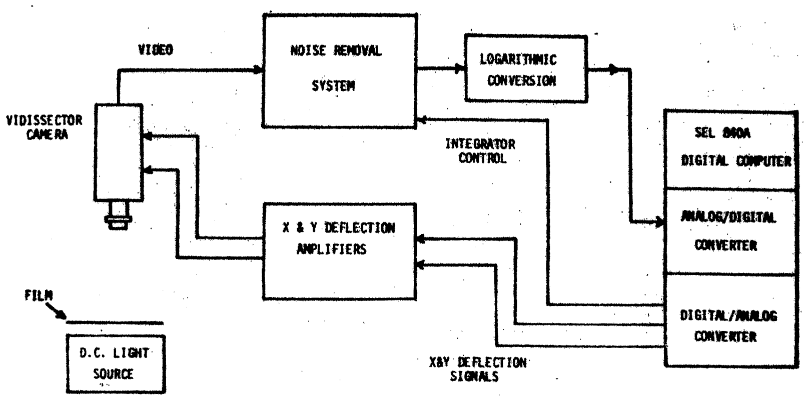
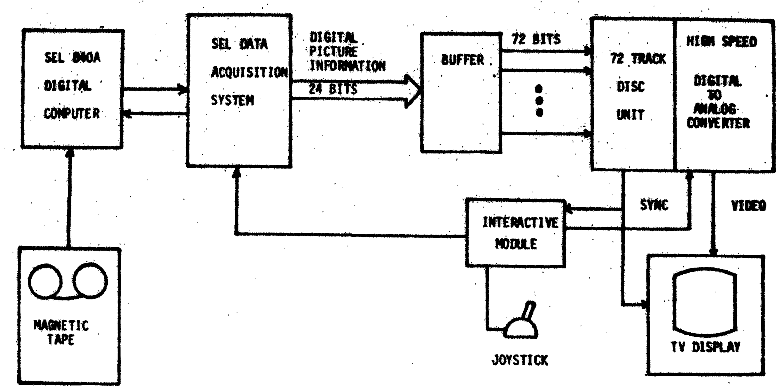


IMAGE DISSECTOR SCANNER SYSTEM (IDS)

FIGURE 3



HIGH SPEED DISC IMAGE DISPLAY SYSTEM

FIGURE 4

FIGURE 5. SEL 840A

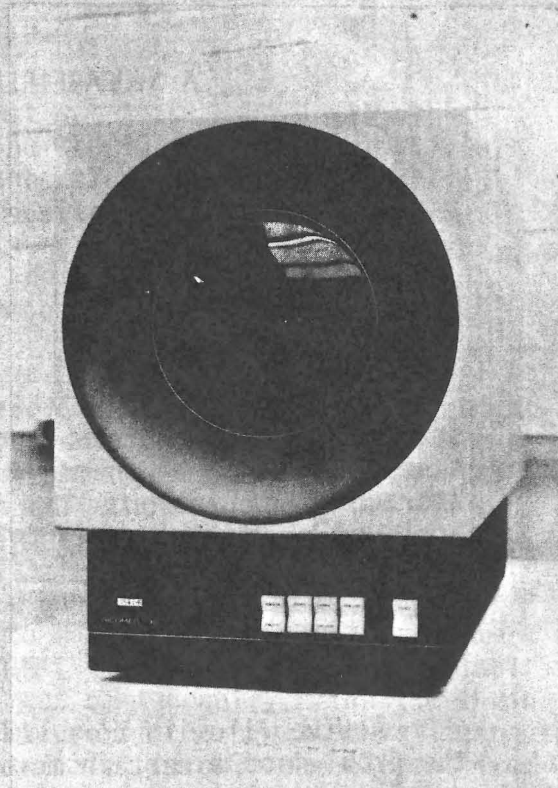


FIGURE 6. DICOMED DISPLAY

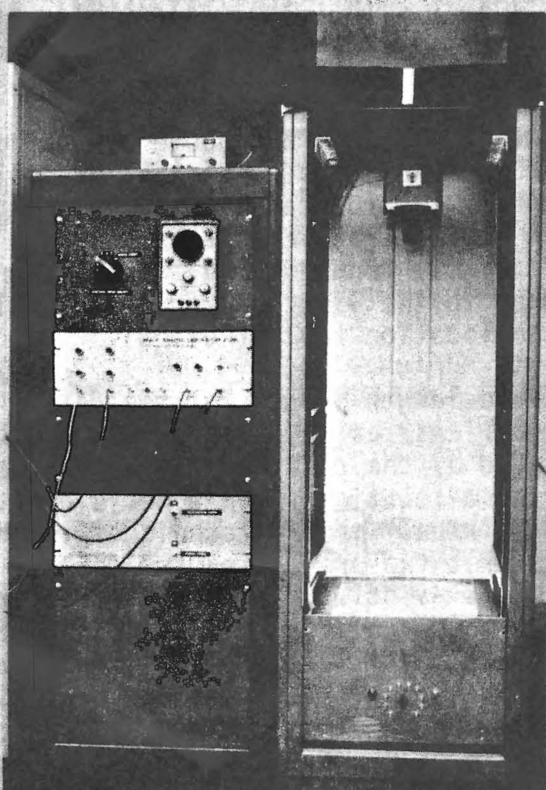


FIGURE 7. IDC SCANNER

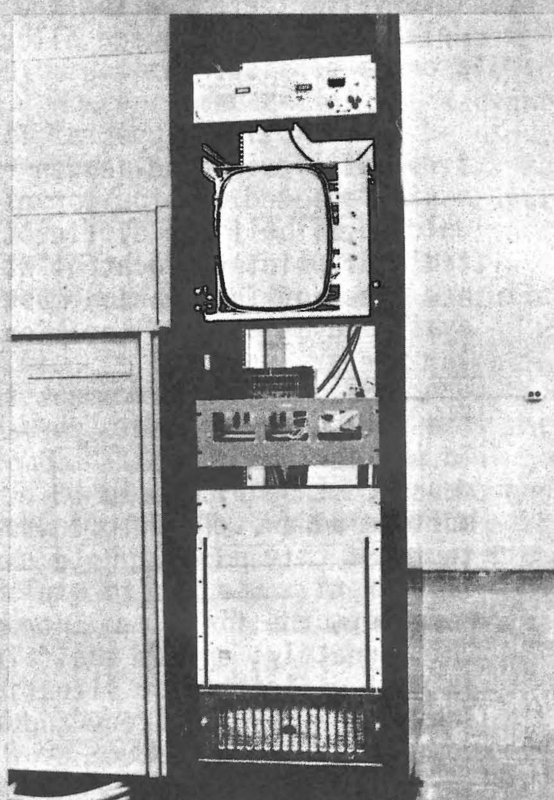


FIGURE 8. DISC-TV DISPLAY